

Ms. Fenix Grange, Program Manager
Hazard Evaluation and Emergency Response Office
Hawaii Department of Health
2385 Waimano Home Road
Pearl City, HI 96782

February 15, 2018

Subject: Comments on the State of the Conceptual Site Model and Related Evaluations for the Navy
 Red Hill Tank Farm Facility, Pearl City, Hawai'i

Dear Ms. Grange:

As requested, I have prepared these comments on the current state of the conceptual site model (CSM) and related evaluations for the Navy Red Hill Tank Farm Facility, Pearl City, Hawai'i. Because I have only been working on this project since December 2017, there may be elements of the Navy's work of which I am unaware that may address some of the issues I raise here. Further, based on our meeting with the Navy on February 8, their technical team may be in the process of addressing some of the concerns raised by me, Robert Whittier, Don Thomas and Matt Tonkin. This review will keep to a relatively high level, as the details are extensive and not as important at this point as are these key observations. My main focus is on jet fuel transport and risk aspects of the CSM.

A related and critical issue is the absence of simple and seamless access to data and existing reports. There does not appear to be any library catalog of existing reports, data, and technical support materials like mapping layers, etc. that is available to the DOH/EPA team. Without that data and information, it is difficult for me and our other experts to fully evaluate scientific findings and conclusions by the Navy team. There are a few documents on the EPA Red Hill website, but nothing comprehensive and with no working digital data.

In summary, the CSM for the Red Hill facility appears to draw preliminary conclusions that are non-conservative, meaning it purports that a robustly protective subsurface hydrogeologic system exists into which a million of gallons of jet fuel could be released without any resultant groundwater damages. While this is an interim conclusion that may change, the Navy's data collection and CSM building seems to be skewed toward investigation of those elements that are protective, but not to the elements that are risk drivers. For instance, the continuity of fractures and bedding plane voids in this volcanic depositional system would be expected to allow for rapid and heterogeneous (likely unpredictable) contaminant transport of both jet fuel and the dissolved-phase plume it would create if it contacts groundwater.

The Navy CSM does not appear representative with respect to local area conditions around the Red Hill tank farm and ridge line. I have not seen a comprehensive analysis of the January 2014 jet fuel release from Tank 5, and the available investigation data points may not even allow for that. But this is one fundamental question for the CSM: a release of an estimated 27,000 gallons of jet fuel occurred, and the Navy has apparently not been able to define the outcomes and impacts of that release. Perhaps the Navy views it as unimportant because they do not observe large groundwater impacts. But that view is limited by a very sparse monitoring and gauging array in the Red Hill Ridge area. The CSM also does not seem to account for releases before 2014, the presence of which have material implications to the CSM as a whole. For instance, past releases will occupy some portion of the residual capacity of the subsurface materials, meaning that there will be less storage (buffering) capacity with respect to future releases.

The biggest single data gap at this time is of a comprehensive geologic analysis of the Red Hill Ridge area. This is a foundational aspect of the CSM and all related evaluations and modeling work. We believe the Navy team has done work in this category, but have not seen the details and cannot as yet understand their geologic model. The geologic evaluations would include items such as those shown in the Table below. Some of these elements have been presented by the Navy team, but most have not. Even for those that have been presented, we do not have access to the underlying data to confirm the Navy's interpretations. Further, some data aspects, such as current LNAPL distribution and others, cannot be well defined at present because of the sparse data network around the Red Hill tanks.

Category	Parameters
Hydrogeology	Aquifer systematics & water balance
	Aquifer parameters (T, K, S, etc.)
	Important transient conditions
	Geochemistry
LNAPL Properties	Density, viscosity, interfacial tensions
	Chemical components of NAPL
Fracture Network	Location of major fracture/bedding sets
	Orientation of fractures/bedding planes
	Fracture aperture & length ranges
	Fracture connectivity & density
Rock Matrix	Primary and secondary porosity
	Transport character of fractures
	Capillary characteristics & wettability
	Residual saturation ranges
LNAPL Distribution	Distribution in fractures
	Distribution in matrix or other features
	Density and character of distribution
	Fingering or other variable conditions
	Areal and vertical aspects of distribution

Adapted after Hardisty, 2003.

My summary interpretation of conditions in the area of the tank farm and Red Hill Ridge are as follows, based on data in available Navy reports. None of these observations appear to be included in the Navy CSM (explicitly nor implicitly), without which the CSM is both incomplete and non-conservative.

- The 2014 release likely impacted groundwater as evidenced by concentration trend increases in some wells following the release (e.g., RHMW01, RHMW02, RHMW03; attached). This is also consistent with associated sharp increases in soil vapor concentrations following the 2014 release (attached, slide deck pg. 21).
- Generally elevated and persistent dissolved-phase concentrations at RHMW02 indicate the presence of jet fuel impacts to groundwater over the full period of monitoring (i.e., jet fuel is in contact with groundwater somewhere in the vicinity).
- Periodic low-level dissolved-phase impacts at the Red Hill Shaft monitoring well suggest distal transport from the tank farm has potentially occurred, supporting the possibility of

a risk-sensitive setting (data attached). These impacts may also be related to the oily waste disposal area, but the point is that the Navy CSM does not appear to consider these data points nor their implied transport and risk potentials.

- Core samples collected beneath each Red Hill tank between 1998 - 2001 exhibit concentrations of petroleum hydrocarbons indicative of separate phase jet fuel at several tank locations and the vertical extent appears undelineated.
- Jet fuel sheens and blebs have been reported during some past monitoring events (personal comm., Robert Whittier).
- Given the above, jet fuel has likely impacted groundwater beneath the tank farm and beyond both from the 2014 and prior releases.

The Navy's current groundwater model does not reflect small-scale conditions evident in the groundwater gradients and flow patterns in the data sets presented. While the model is useful from a bulk flow perspective, its inability to characterize measured conditions suggests real-world complexities in groundwater flow remain unconsidered. These complexities are the actual hydrogeologic elements that will have a direct impact on contaminant transport. Because the model cannot at its present discretization/scale represent these conditions, any contaminant transport modeling will be of limited value. Matt Tonkin, Bob Whittier and Don Thomas all have detailed groundwater model comments and I will not delve further into this particular subject in this review.

The nonaqueous phase liquid (NAPL, a.k.a., fuels and petroleum products) aspects of the CSM similarly fail to address key technical issues of potential migration complexities. The Navy team framed its LCSM analysis in the form of a key question: *"What is the size of the largest, sudden release that would not result in unacceptable risks to groundwater receptors?"* Their preliminary answer, based on the analysis presented on January 11, 2018 was: *"Potentially over a million gallons, depending on scenario"* (GSI, January 11, 2018). *The second Navy question of chronic releases is not discussed here.*

There are several issues with the LCSM that make it non-conservative and non-representative. First, LNAPL migration in this particular environment is expected to be complex and the simplified LNAPL compartment/residualization model used by the Navy team ignores those complexities. LNAPL flow is often fingered, heterogenous, and unpredictable as shown in my February 8, 2018 slide deck (attached). The analysis by the Navy is not a dynamic release model. Rather, it is a simplified compartment model where layers of subsurface materials are assumed to residualize (absorb) LNAPL as it passes by. The method has no transient, release dependent aspects, nor does it account for any of the processes that likely make LNAPL transport a significant risk at this site. Their conclusion above is directly refuted by available site data that show the 2014 release of ~27,000 gallons impacted groundwater shortly thereafter, orders of magnitude smaller than the million gallons concluded above. Further, their model does not account for residual LNAPL already in the pore space, as evidenced by past subsurface sampling and by inference that some fraction of the 2014 release is stored as residual in the area of Tank 5. While LNAPL may be biologically degraded, not all components are amenable to those processes and regardless, time is required for mass to be depleted (transient aspects were not considered). The conservative assumption, based on field data, is that some fraction of the available residual capacity is already occupied.

At the time of the Navy's LCSM presentation, no site specific petrophysical data had been collected. We understand those data are presently being generated through core and petrophysical testing. There are

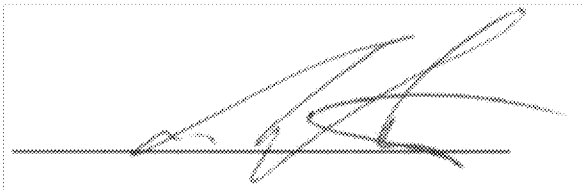
several technical reasons to suggest these data may be non-conservative. I hope to be able to work with the Navy team to consider these issues that include:

- Conditions of testing often are not reflective of release conditions and can overestimate parameters like residual saturation, which is a function of pressure and saturation history.
- Lithologic cores are a small-scale representation of a much larger system, and lab test values are often at odds with field scale test results (and often non-conservatively).
- The selection of cores and fractures needs to be considered within the context of the geologic model details, which as noted, we do not have.
- Capillary centrifuge testing methods often used by petrophysical labs have come under suspicion because those results conflict with other well-documented results.

In summary as it stands, the Navy's CSM/LCSM appears to be non-conservative and arrives at protective conclusions that are at odds with site data and conditions. While I recognize good data and work have been done by the Navy, the unavailability of that information for independent review impedes my ability to concur with various aspects of the CSM. Based on site data and work elsewhere in fractured rock settings, this particular site is more likely a high potential risk with respect to groundwater resources. There are indications of large distal transport of jet fuel components, groundwater impacts caused by a relatively small LNAPL release, and a general setting that suggests complex and rapid contaminant transport is likely. Until the Navy CSM embraces that potential, I will be unable to concur with their primary conclusions.

The opportunity to be of service is appreciated, please call if you have questions.

AQUI-VER, INC.

A handwritten signature in black ink, appearing to read 'G.D. Beckett', is written over a horizontal line. The signature is stylized with long, sweeping strokes.

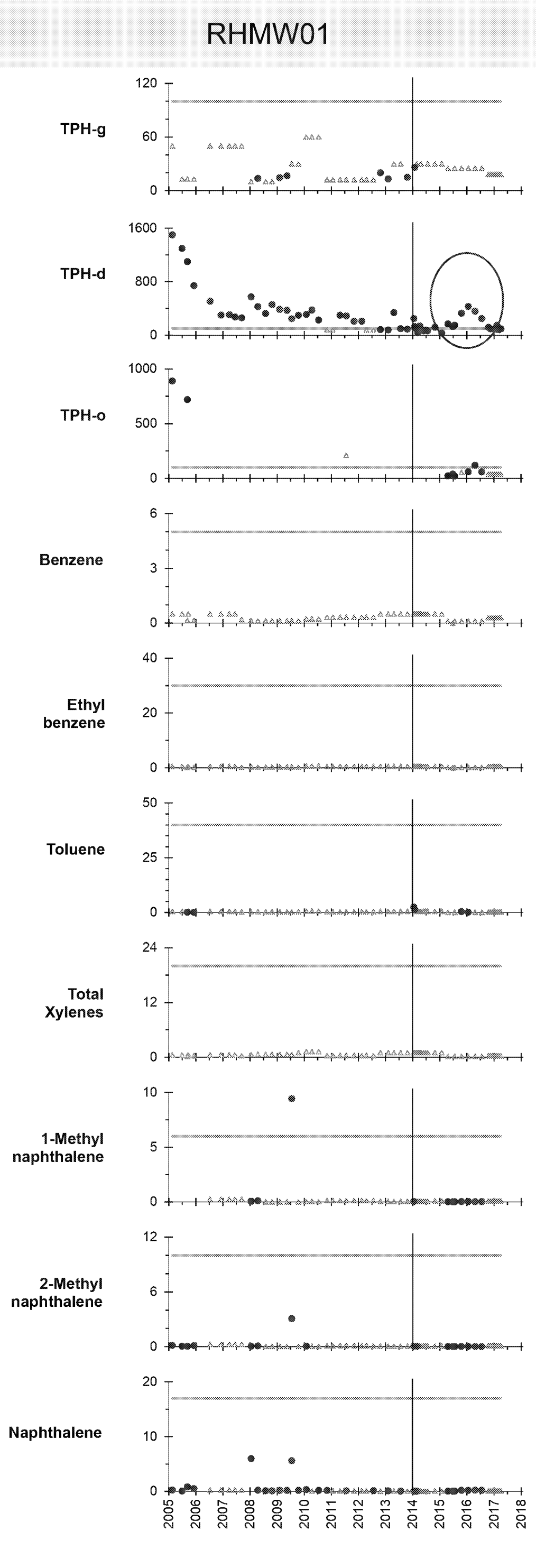
G.D. Beckett, CHg
Principal Hydrogeologist

cc: Ms. Lene K Ichinotsubo, HDOH
Mr. Bob Whittier, HDOH

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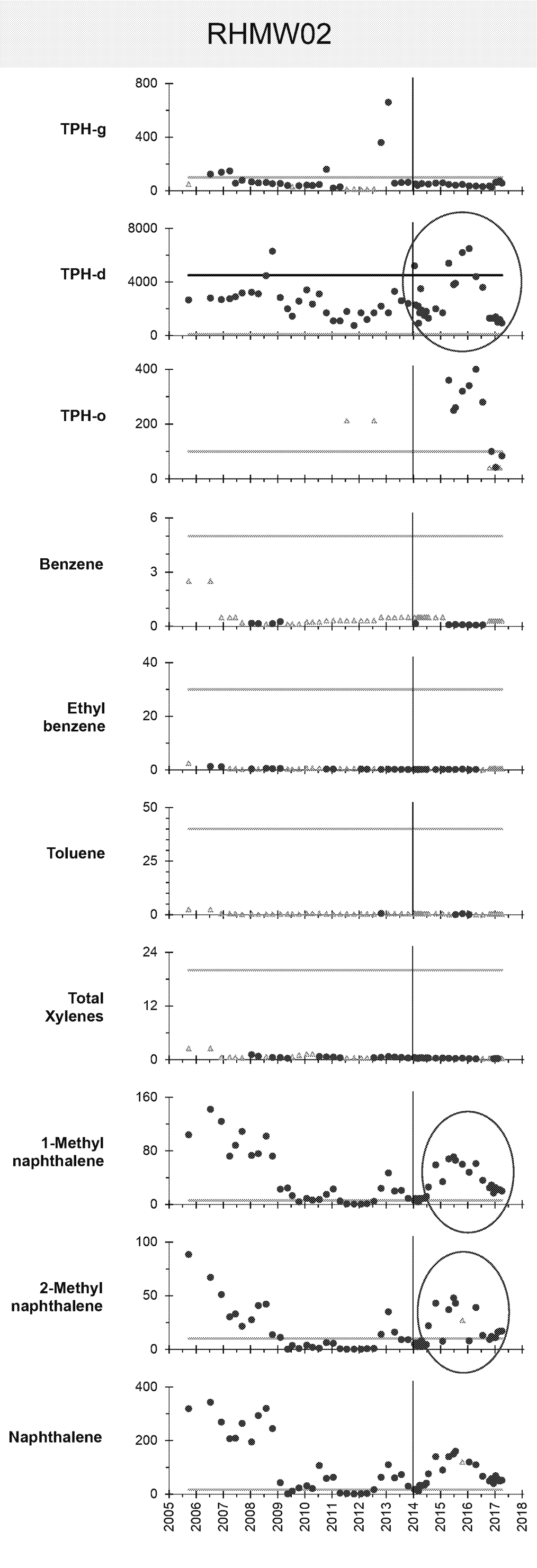
ATTACHMENTS

Well Concentration Trends
Analytic Data: RHMW2254-01
LNAPL Transport Slides - G.D. Beckett

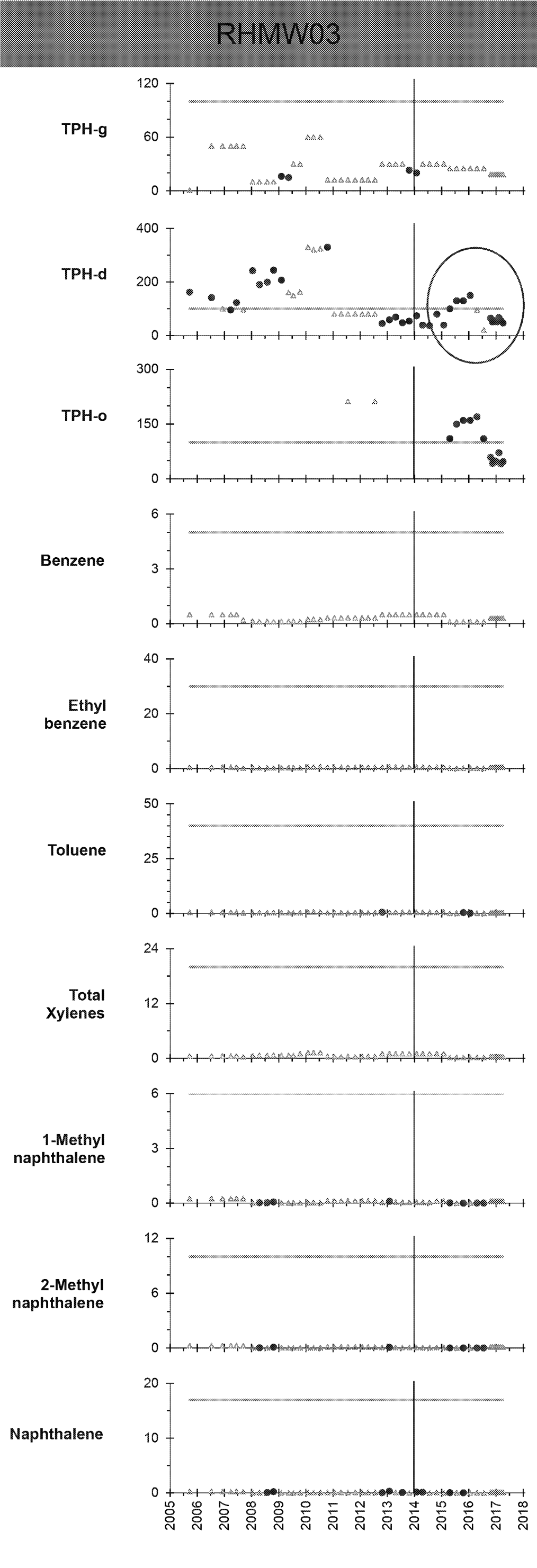


All units in micrograms per liter (ug/L or parts per billion).

Detections increased, scale does not allow trend observation.



All units in micrograms per liter (ug/L or parts per billion).



Detections increased, scale does not allow trend observation.

All units in micrograms per liter (ug/L or parts per billion).

Appendix A.1: Cumulative Groundwater COPC Results
Second Quarter 2017 - Quarterly Groundwater Monitoring Report, Red Hill Bulk Fuel Storage Facility, JBPHH, O'ahu, Hawai'i

Method			8015							8260							8260SIM			8011			8270			8270/8270 Mod.													
Unit			TPH-d (µg/L)		TPH-g **** (µg/L)		TPH-o (µg/L)		TPH-g **** (µg/L)		1,2-Dibromoethane ***** (µg/L)		1,2-Dichloroethane ***** (µg/L)		Benzene (µg/L)		Ethylbenzene (µg/L)		Naphthalene (µg/L)		Toluene (µg/L)		Xylenes, Total (p/m-, o-xylene) (µg/L)		1,2-Dibromoethane ***** (µg/l)		1,2-Dichloroethane ***** (µg/L)		1,2-Dibromoethane ***** (µg/L)		1-Methylnaphthalene (µg/L)		2-Methylnaphthalene (µg/L)		Naphthalene (µg/L)		Phenol (µg/L)		2-(2-Methoxyethoxy)- ethanol (µg/L)
Screening Criterion			100		100		100		100		0.04		5.0		5.0		30		17		40		20		0.04		5.0		0.04		6		10		17		300		800
SSRBL			4500		—		—		—		—		—		750		—		—		—		—		—		—		—		—		—		—		—		—
Well Name	Sample ID	Sampled	Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result		Result
RHMW2254-01	RH-B-001	2/16/2005 ^{ba}	< 50	U	< 50	U	< 100	U	—		<0.0083	U	< 0.50	U	< 0.50	U	< 0.50	U	—		1.0		< 0.50	U	—		—		—		—		< 0.020	U	< 0.020	U	—		—
	RH-B-002	2/16/2005 ^{bf}	< 53	U	< 50	U	<110	U	—		<0.0081	U	< 0.50	U	< 0.50	U	< 0.50	U	—		1.2		< 0.50	U	—		—		—		—		< 0.022	U	< 0.022	U	—		—
	RH-B-003	2/16/2005 ^{*bf}	< 50	U	< 50	U	< 100	U	—		<0.0082	U	< 0.50	U	< 0.50	U	< 0.50	U	—		0.81		< 0.50	U	—		—		—		< 0.021	U	< 0.021	U	—		—		
	RH-B-004	6/28/2005 ^{ae}	43	J	< 13	U	—		—		< 0.00096	U	<0.50 ^b	U	<0.50 ^b	U	<0.50 ^b	U	—		<0.50 ^b	U	<0.50 ^b	U	—		—		—		<0.020 ^b	U	<0.020 ^b	U	—		—		
	RH-B-005	6/28/2005 ^{*ae}	67	Z	< 13	U	—		—		< 0.00096	U	<0.50 ^b	U	<0.50 ^b	U	<0.50 ^b	U	—		<0.50 ^b	U	<0.50 ^b	U	—		—		—		<0.020 ^b	U	<0.020 ^b	U	—		—		
	RH-B-006	6/28/2005 ^{*af}	58	Z	< 13	U	—		—		< 0.00096	U	<0.50 ^b	U	<0.50 ^b	U	<0.50 ^b	U	—		<0.50 ^b	U	<0.50 ^b	U	—		—		—		<0.021 ^b	U	<0.021 ^b	U	—		—		
	RH-B-007	9/8/2005 ^{ae}	45	J	< 13	U	59	J	—		< 0.00096	U	< 0.12	U	< 0.14	U	< 0.13	U	—		< 0.11	U	< 0.22	U	—		—		—		<0.020 ^b	U	0.085		—		—		
	RH-B-008	9/8/2005 ^{af}	< 50	U	< 13	U	<28	U	—		< 0.00096	U	< 0.12	U	< 0.14	U	< 0.13	U	—		< 0.11	U	< 0.22	U	—		—		—		<0.020 ^b	U	<0.020 ^b	U	—		—		
	RH-B-009	9/8/2005 ^{*af}	<50 ^d	U	< 13	U	<100 ^d	U	—		< 0.00096	U	< 0.12	U	< 0.14	U	< 0.13	U	—		< 0.11	U	< 0.22	U	—		—		—		<0.020 ^b	U	0.045		—		—		
	RHMW2254W01	9/20/2005 ^{bcd}	—		—		—		—		< 0.50	U	< 0.50	U	< 0.50	U	< 0.50	U	< 1.0	U	< 0.50	U	< 0.50	U	—		—		—		—		—		—		—		
	RH-B-010	12/6/2005 ^{ae}	38	J	< 13	U	—		—		<0.0096 ^b	U	< 0.12	U	< 0.14	U	< 0.13	U	—		< 0.11	U	< 0.22	U	—		—		—		0.038		0.036		—		—		
	RH-B-011	12/6/2005 ^{*ae}	24	J	< 13	U	—		—		<0.0094 ^b	U	< 0.12	U	< 0.14	U	< 0.13	U	—		< 0.11	U	< 0.22	U	—		—		—		0.022		0.024		—		—		
	RH-B-012	12/7/2005 ^{af}	< 20	U	< 13	U	—		—		<0.0095 ^b	U	< 0.12	U	< 0.14	U	< 0.13	U	—		< 0.11	U	< 0.22	U	—		—		—		0.0071	J	0.011	J	—		—		
	RHMW2254-01-GW02	7/10/2006 ^{ad}	< 110	U	< 50	U	—		—		< 0.50	U	< 0.50	U	< 0.50	U	< 0.50	U	< 1.0	U	< 0.50	U	< 0.50	U	—		—		< 0.26	U	< 0.26	U	< 0.26	U	—		—		
	RHMW2254-01-GW06	12/5/2006 ^{ad}	< 100	U	< 50	U	—		—		< 0.50	U	< 0.50	U	< 0.50	U	< 0.50	U	< 1.0	U	< 0.50	U	< 0.50	U	—		—		< 0.25	U	< 0.25	U	< 0.25	U	—		—		
	RHMW2254-01-WG07	3/27/2007 ^a	< 98	U	< 50	U	—		—		< 0.50	U	< 0.50	U	< 0.50	U	< 0.50	U	< 1.0	U	< 0.50	U	< 0.50	U	—		—		< 0.24	U	< 0.24	U	< 0.24	U	—		—		
	RHMW2254-01-WG08	6/12/2007 ^a	< 98	U	< 50	U	—		—		< 0.50	U	< 0.50	U	< 0.50	U	< 0.50	U	< 1.0	U	< 0.50	U	< 0.50	U	—		—		< 0.25	U	< 0.25	U	< 0.25	U	—		—		
	RHMW2254-01-WG0	9/10/2007 ^a	< 97	U	< 50	U	—		—		< 0.20	U	< 0.20	U	< 0.20	U	< 0.20	U	< 0.44	U	< 0.27	U	< 0.36	U	—		—		< 0.25	U	< 0.25	U	< 0.25	U	—		—		
	RHMW2254-01-WG10	1/15/2008 ^a	< 102	U	< 10.0	U	—		—		< 0.310	U	< 0.150	U	< 0.120	U	< 0.310	U	< 0.620	U	< 0.310	U	< 0.620	U	—		—		< 0.0150	U	< 0.0150	U	< 0.0310	U	—		—		
	RHMW2254-01-WG10.1	2/6/2008 ^a	< 100	U	—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		
	RHMW2254-01-WG10.1	2/6/2008 ^a	< 10.3	U	—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		
	RHMW2254-01-WG11	4/15/2008 ^a	< 86.0	U	< 10.0	U	—		—		< 0.310	U	< 0.150	U	< 0.120	U	< 0.310	U	< 0.620	U	< 0.310	U	< 0.620	U	—		—		0.0435	J	0.0561		< 0.0332	U	—		—		
	RHMW2254-01-WG12	7/29/2008 ^a	< 83.3	U	< 10.0	U	—		—		< 0.310	U	< 0.150	U																									

Appendix A.1: Cumulative Groundwater COPC Results (cont'd)
Second Quarter 2017 - Quarterly Groundwater Monitoring Report, Red Hill Bulk Fuel Storage Facility, JBP HH, O'ahu, Hawai'i

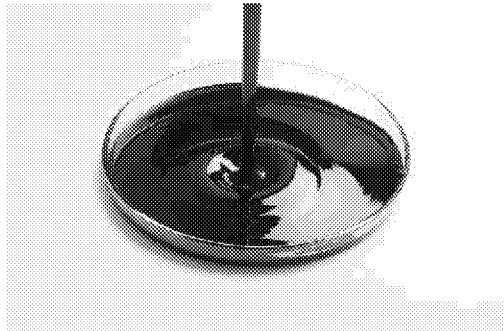
Method			8015						8260						8260SIM			8011	8270			8270/8270 Mod.												
Unit			TPH-d	TPH-g ****		TPH-o	TPH-g ****		1,2-Dibromoethane *****		1,2-Dichloroethane *****		Benzene	Ethylbenzene	Naphthalene		Toluene	Xylenes, Total (p/m-, o-xylene)	1,2-Dibromoethane *****	1,2-Dichloroethane *****	1,2-Dibromoethane *****	1-Methylnaphthalene	2-Methylnaphthalene	Naphthalene		Phenol	2-(2-Methoxyethoxy)-ethanol							
Screening Criterion			100	100		100	100		0.04		5.0		5.0	30	17		40	20	0.04	5.0	0.04	6	10	17		300	800							
SSRBL			4500	—		—	—		—		—		750	—	—		—	—	—	—	—	—	—	—		—	—							
Well Name	Sample ID	Sampled	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result							
RHMW2254-01 (cont'd)	ES094	5/28/2014	< 12	U	—	—	—	—	—	< 0.50	U	< 0.50	U	—	< 0.50	U	< 1.0	U	—	—	—	< 0.050	U	< 0.050	U	< 0.050	U	—	—					
	ES102	6/24/2014	< 12	U	—	—	—	—	—	< 0.50	U	< 0.50	U	—	< 0.50	U	< 1.0	U	—	—	—	< 0.049	U	< 0.049	U	< 0.049	U	—	—					
	ES107	7/22/2014	< 12	U	—	—	—	< 30	U	< 0.50	U	< 0.50	U	—	< 0.50	U	< 1.0	U	—	—	—	< 0.048	U	< 0.048	U	< 0.048	U	—	—					
	ES117	10/28/2014	22	J,HD	—	—	—	< 30	U	< 0.50	U	< 0.50	U	—	< 0.50	U	< 1.0	U	—	—	—	< 0.097	U	< 0.049	U	< 0.049	U	—	—					
	ES125	1/27/2015	< 12	U	—	—	—	< 30	U	< 0.50	U	< 0.50	U	—	< 0.50	U	< 1.0	U	—	—	—	< 0.10	U	< 0.050	U	< 0.050	U	—	—					
	ES134	4/21/2015	14	BJ	< 25	U	37	BJ	—	< 0.20	U	—	< 0.10	U	< 0.10	U	—	< 0.10	U	< 0.010	U	< 0.015	U	< 0.0040	U	< 0.0050	UJ	< 0.0050	UJ	—	—			
	ES149	7/21/2015	17	J	< 25	U	42	J	—	< 0.20	U	—	< 0.10	U	< 0.10	U	—	< 0.10	U	< 0.015	U	< 0.0040	U	< 0.0050	U	< 0.0050	U	< 0.0050	U	—	—			
	ERH009	10/20/2015	16	BJ	< 25	U	< 53	UB	—	< 0.20	U**	—	< 0.10	U**	< 0.10	U**	—	0.990	Tb**	< 0.20	U**	—	< 0.015	U	< 0.0040	U	< 0.0050	U	< 0.0050	UB	< 0.0050	UB	—	—
	ERH021	1/20/2016	21	BJ	< 25	U	< 54	UB	—	< 0.20	U	—	< 0.10	U	< 0.10	U	—	0.16	TbJ	< 0.20	U	—	< 0.015	U	< 0.0040	U	< 0.0050	U	< 0.0050	U	< 0.0050	U	—	—
	ERH037	4/20/2016	< 21	UB	< 25	U	< 61	UB	—	—	< 0.10	U	0.10	J	—	< 0.10	U	< 0.20	U	—	—	< 0.0050	U	< 0.0050	U	< 0.0050	U	< 0.0050	U	—	—			
	ERH051	7/20/2016	< 21	U	< 25	U	< 52	UBF	—	—	< 0.10	U	< 0.10	U	—	< 0.10	U	< 0.20	U	—	—	—	< 0.0050	U	< 0.0050	U	< 0.0050	UBF	—	—	—	—		
	ERH088/092	10/18/2016*	< 25	U	—	< 40	U	< 18	UJ	—	< 0.30	U	< 0.50	U	—	< 0.30	U	< 0.30	U	—	—	—	< 0.10	U	< 0.10	U	< 0.10	U	< 4.00	U	< 80.0	UJ	—	—
	ERH115/116	11/14/2016*	< 25	U	—	< 40	U	< 18	U	—	< 0.30	U	< 0.50	U	—	< 0.30	U	< 0.30	U	—	—	—	< 0.10	U	< 0.10	U	< 0.10	U	< 4.00	U	< 80.0	U	—	—
	ERH135/137	12/12/2016*	14	J	—	—	16	J	< 18	U	< 0.30	U	< 0.50	U	—	< 0.30	U	< 0.30	U	—	—	—	< 0.10	U	< 0.10	U	< 0.10	U	< 4.00	U	< 80.0	U	—	—
	ERH161/162	1/10/2017*	< 25	U	—	< 40	U	< 18	U	—	< 0.30	U	< 0.50	U	—	< 0.30	U	< 0.30	U	—	—	—	< 0.10	U	< 0.10	U	< 0.10	U	< 4.00	U	< 80.0	U	—	—
	ERH205/206	2/7/2017*	< 25	U	—	< 40	U	< 18	U	—	< 0.30	U	< 0.50	U	—	< 0.30	U	< 0.30	U	—	—	—	< 0.10	U	< 0.10	U	< 0.10	U	< 4.00	U	< 80.0	U	—	—
ERH257/258	3/6/2017	< 25	U	—	< 40	U	< 18	U	—	< 0.30	U	< 0.50	U	—	< 0.30	U	< 0.30	U	—	—	—	< 0.10	U	< 0.10	U	< 0.10	U	< 4.00	U	< 80.0	U	—	—	
ERH292/293	4/3/2017	< 25	U	—	< 40	U	< 18	U	—	< 0.30	U	< 0.50	U	—	< 0.30	U	< 0.30	U	—	—	—	< 0.10	U	< 0.10	U	< 0.10	U	< 4.00	U	< 80.0	U	—	—	

Considerations on LNAPL Transport at the Navy Red Hill Facility

Presented to:
Hawai'i Department of Health, EPA & Interested Parties

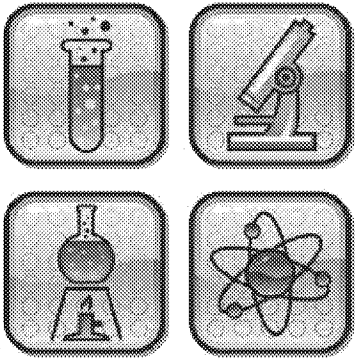
February 8, 2018
G.D. Beckett, PG, CHG
AQUI-VER, INC.

Topics



- Overview of preliminary Navy LCSM
- LNAPL migration complexities
 - Particularly in this type of setting
 - Apparent absence of key site parameters
- Indications provided by site data
 - Potential LNAPL impact to g.w.
 - Potential directions of migration
- Implications
- *We cannot know/describe everything*
 - *But we can evaluate important aspects*
 - *Conservatively infer or measure*

Some General Observations by Others



- Pore scale processes are important
 - But won't be seen at macro-scale
 - Homogenization can yield insights, but limited
- Heterogeneity **cannot** be modeled deterministically
 - Micro-scale phenomena appear semi-random
 - Stochastic approaches should be considered
 - *Abbreviated from Russell et al., NSF (2008)*
- Small volumes of LNAPL in ~vertical fractures can produce significant LNAPL heads:
 - Significant depth of penetration into aquifer possible
 - Monitoring well observations are not straightforward
- The presence of potentially mobile LNAPL beneath historical groundwater surface lows should be considered
 - *Abbreviated from Hardisty et al., J. of Eng. Geo & Hydro 2003*

JANUARY 2014 RELEASE

SPECIFIC RETENTION ANALYSIS

120

Apply three different volume scenarios holding spilled LNAPL:

Scenario A (Least Conservative):

13 cubic feet basalt needed to hold one gallon LNAPL

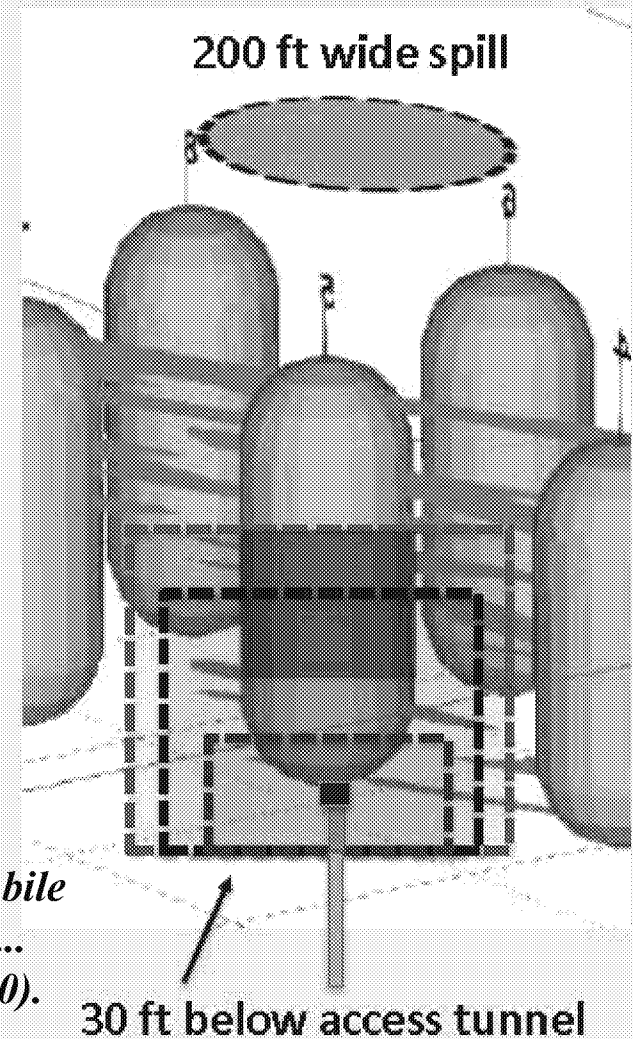
Scenario B: (Most Likely)

20 cubic feet basalt needed to hold one gallon LNAPL

Scenario C: (Most Conservative)

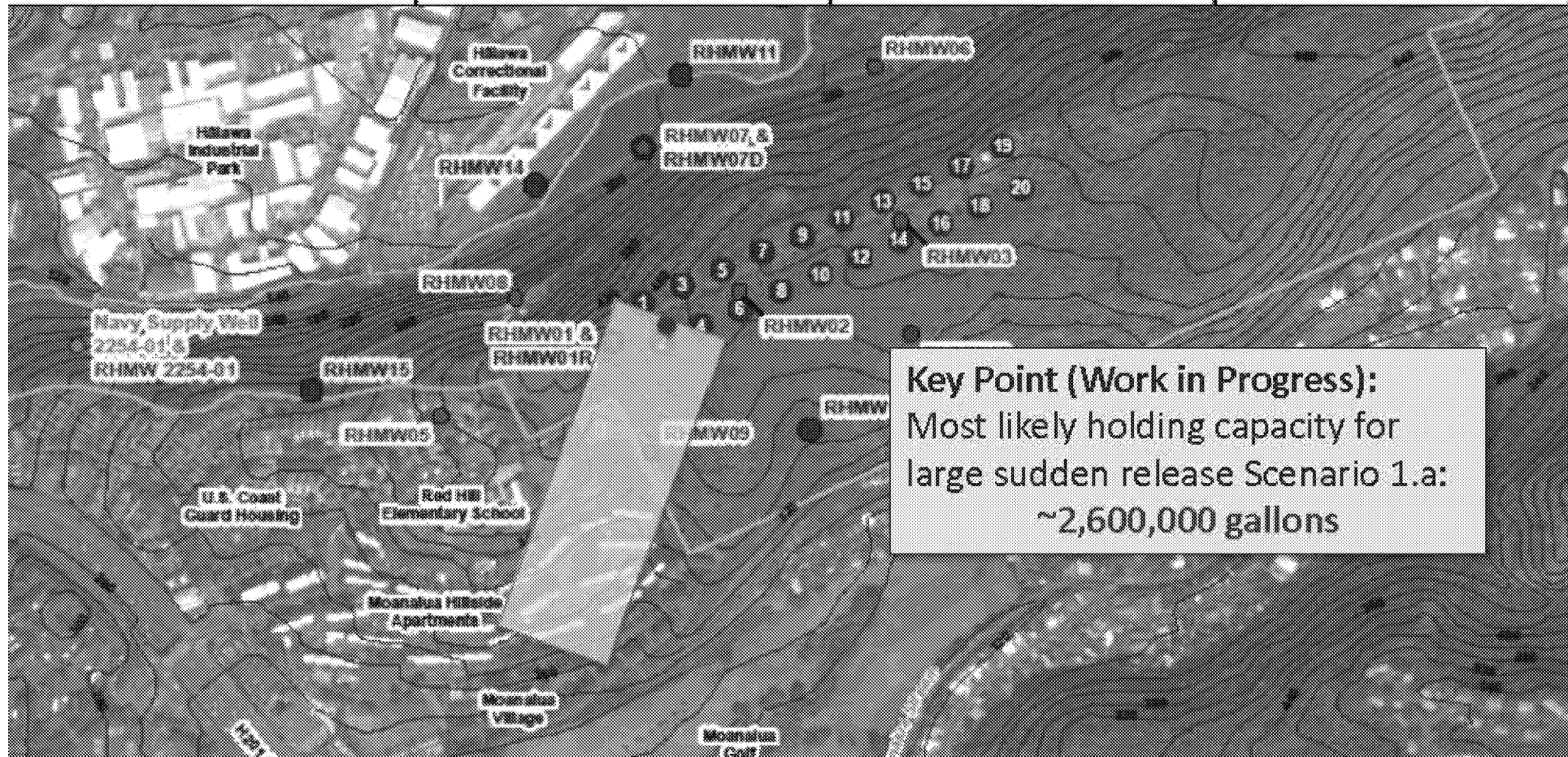
53 cubic feet basalt needed to hold one gallon LNAPL

Use of residual NAPL concentration in soil values for screening immobile (retained) NAPL presumes homogenous soils.. Macropores, fractures ... must be recognized in applications. (paraphrased from API Bul 9, 2000).

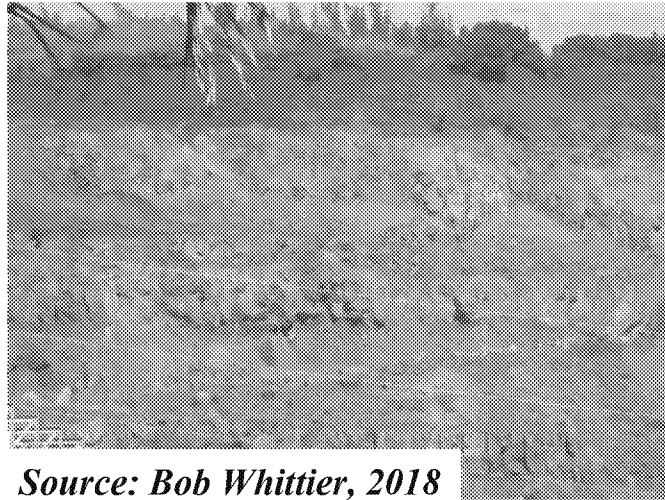


HYPOTHETICAL LARGE SUDDEN RELEASE HOLDING CAPACITY RESULTS FOR SCENARIO 1

Hypothetical LNAPL Release Scenario	This is the Maximum Release Volume That Will:	Mostly Likely LNAPL Holding Capacity (gallons)	10 th to 90 th Percentile Range (gallons)
Scenario 1a (Low Release)	Protect users of groundwater in the vicinity of the Facility	2,600,000	1,900,000 - 3,600,000



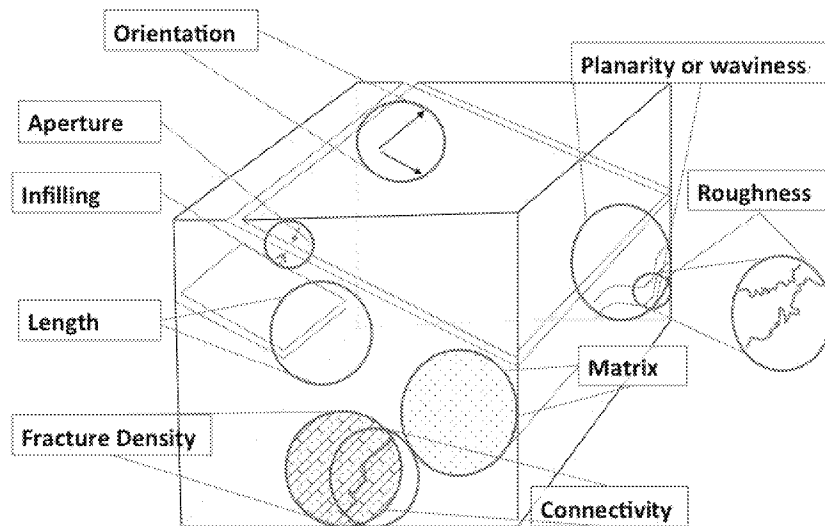
Factors Affecting Flow Heterogeneity



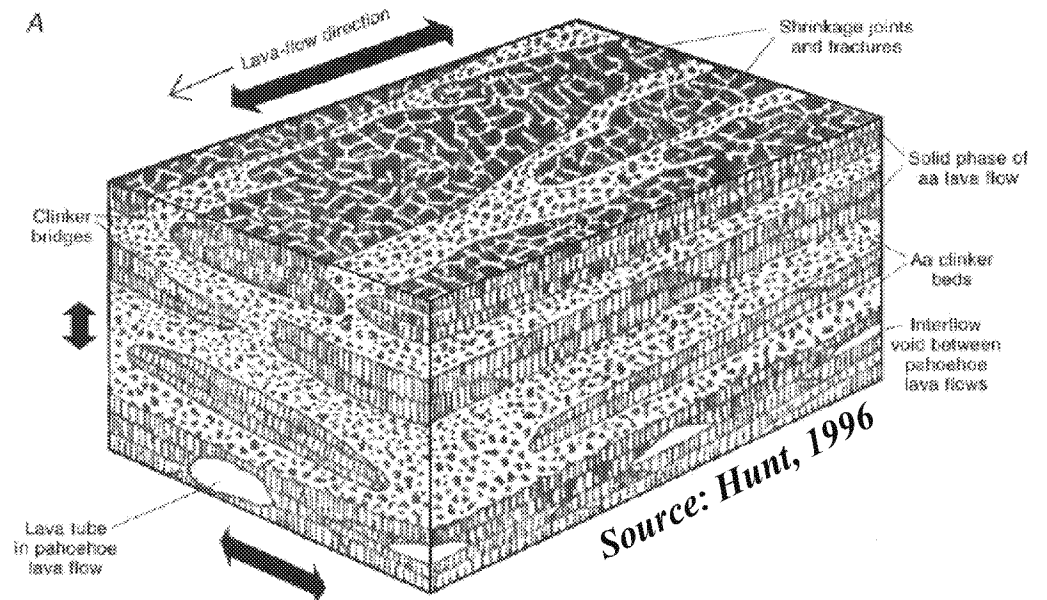
Source: Bob Whittier, 2018



Source: Matt Tonkin, 2018

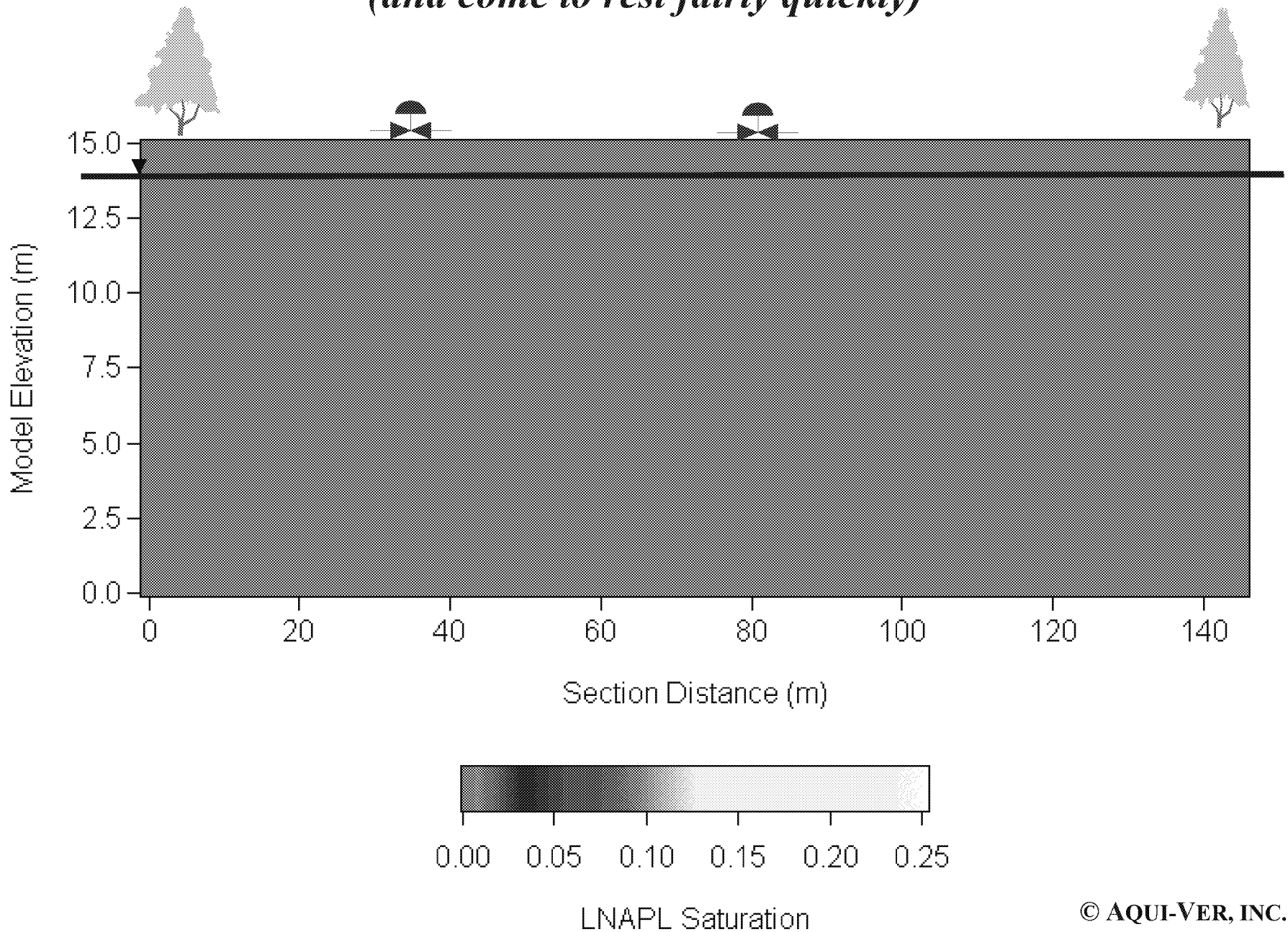


Source: ITRC, 2017



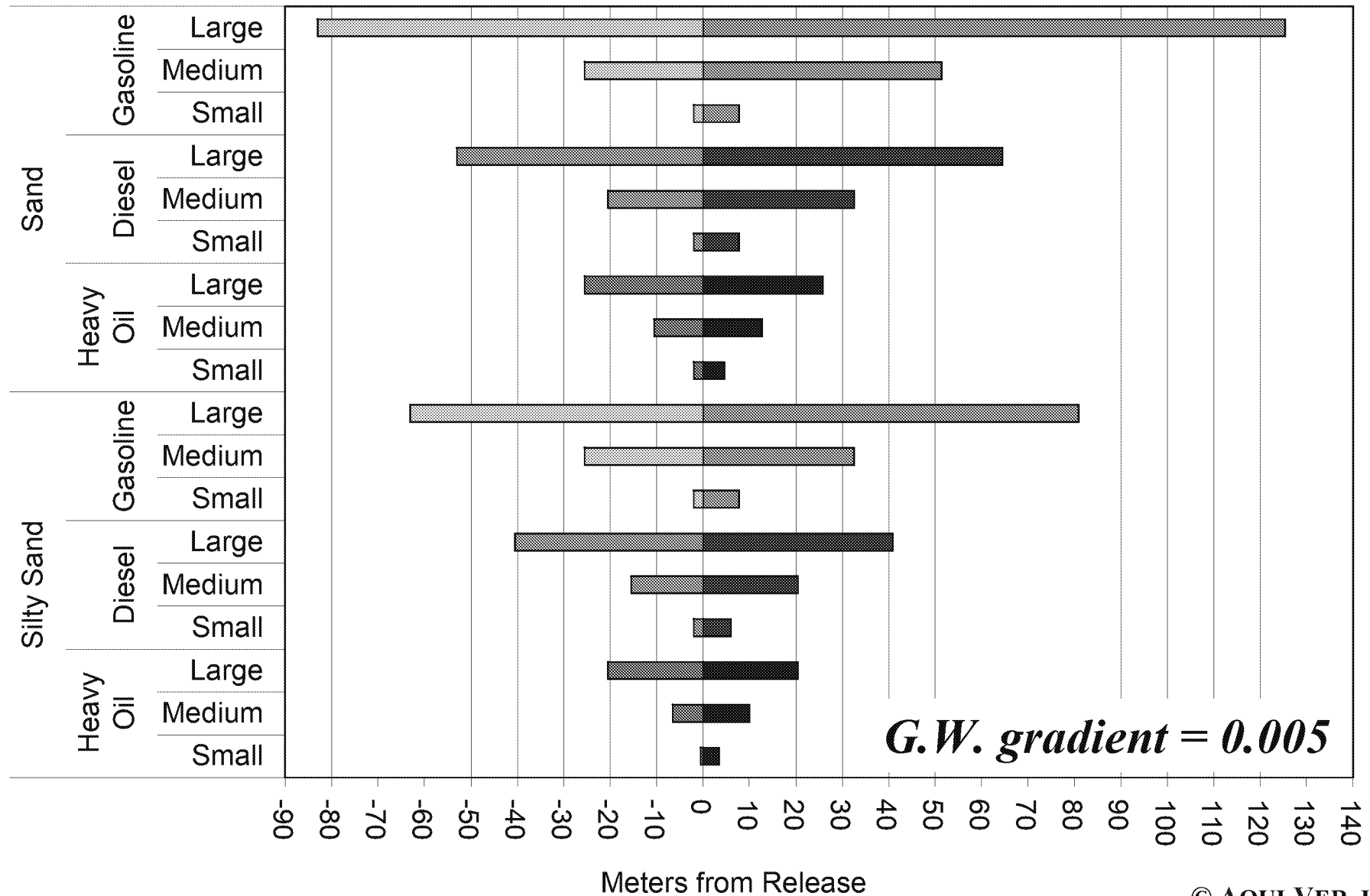
Source: Hunt, 1996

LNAPL Release Are Highly Transient *(and come to rest fairly quickly)*



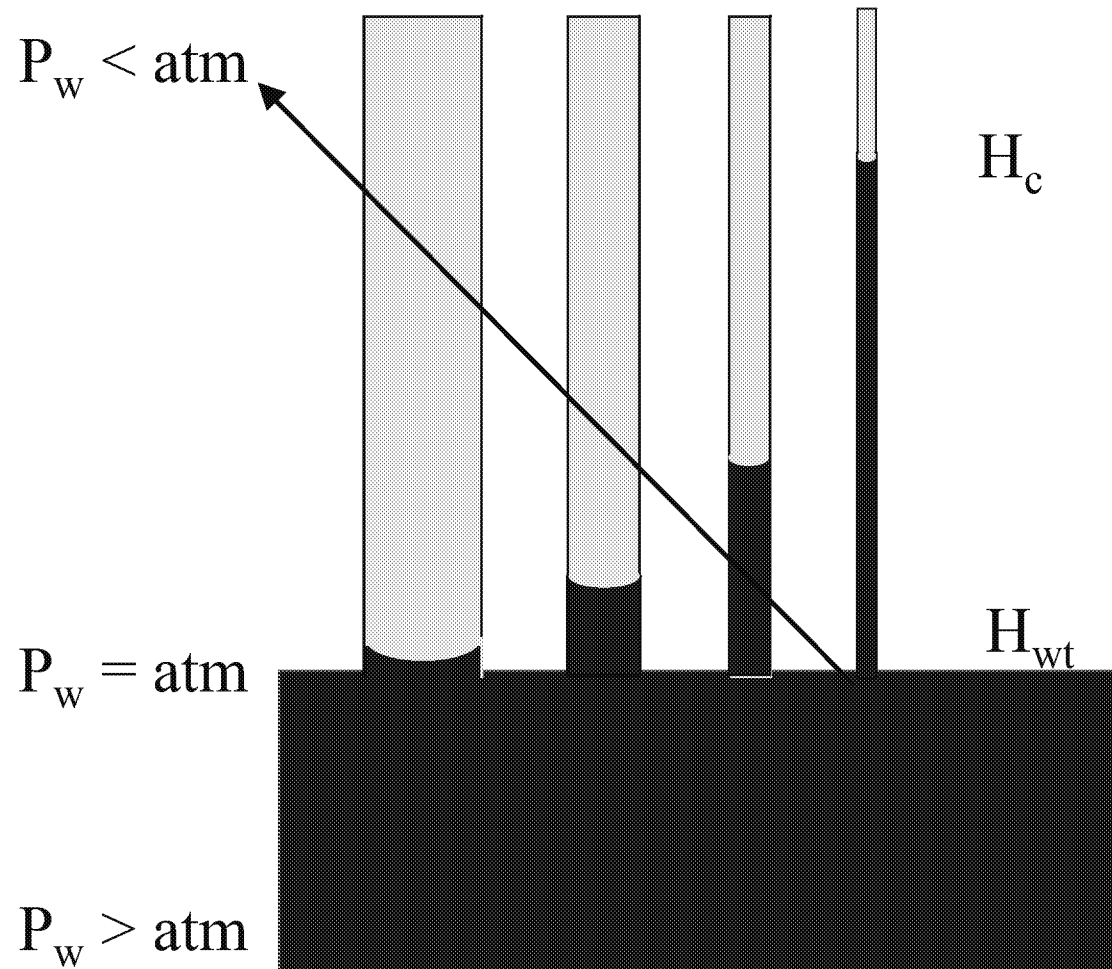
Comparative Lateral LNAPL Migration

(converse is true for vertical migration)



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Importance of Capillarity - Wettability



As pore or aperture size gets smaller, capillary rise gets bigger. Harder for NAPL to enter small pores, requires greater pressure.

Wetting Phase Importance

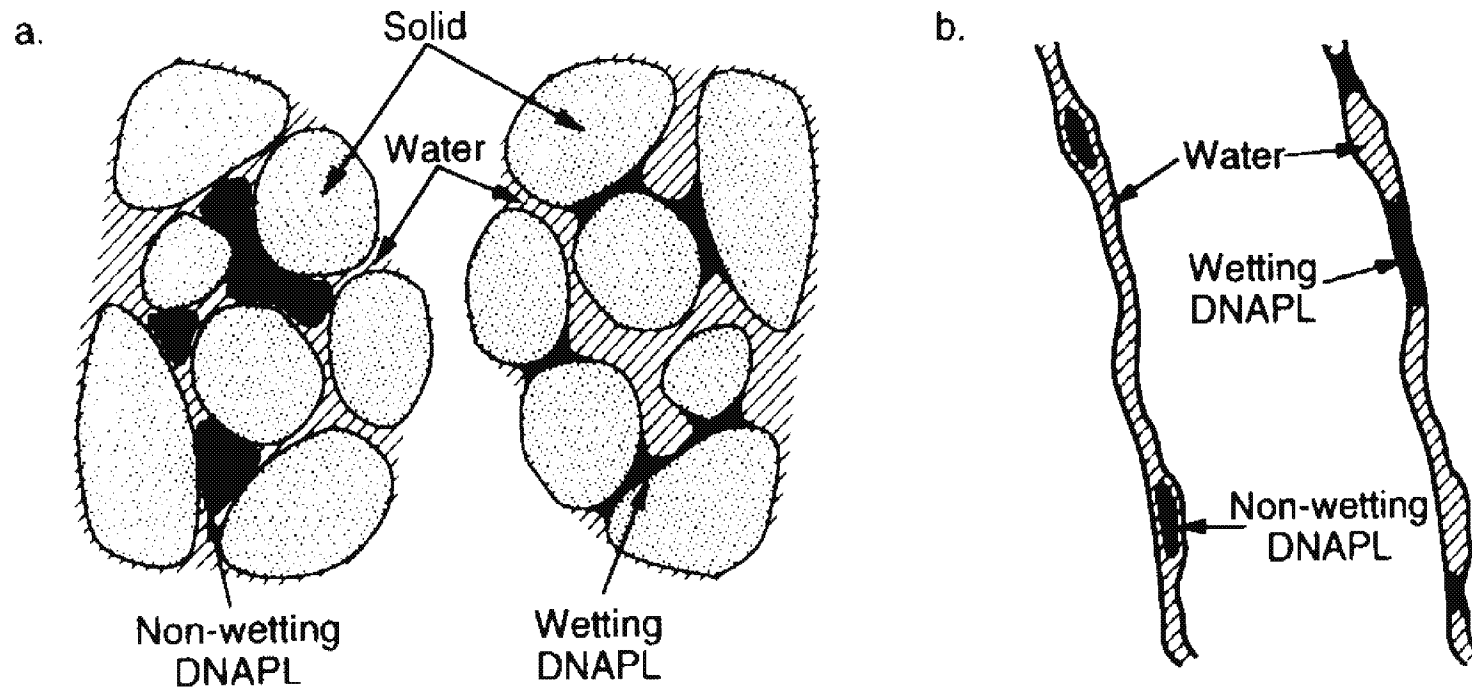


Figure 2.3 Pore-scale representation of non-wetting and wetting DNAPL residual in: a) water-saturated sand; and b) a fracture.

after Pankow & Cherry, 1996

Initial vs. Residual Saturation Relationship (for these specific study soils & oils)

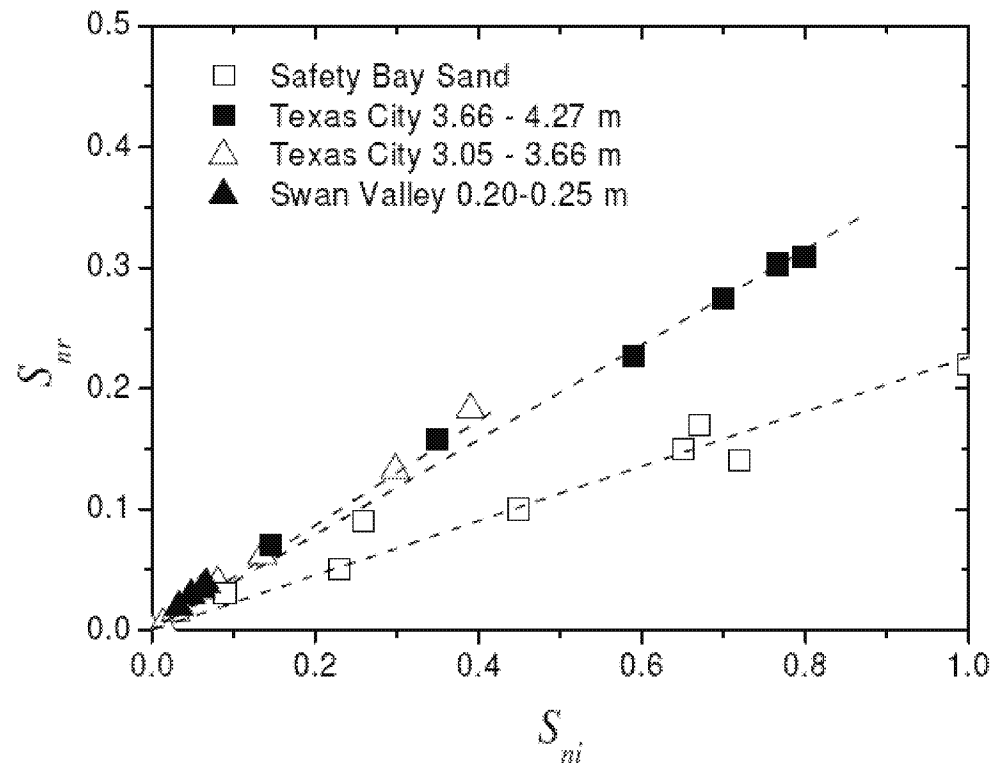
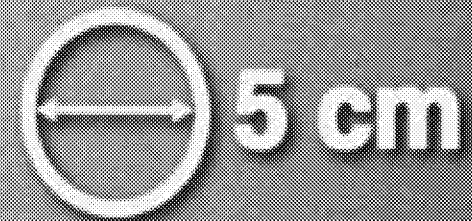
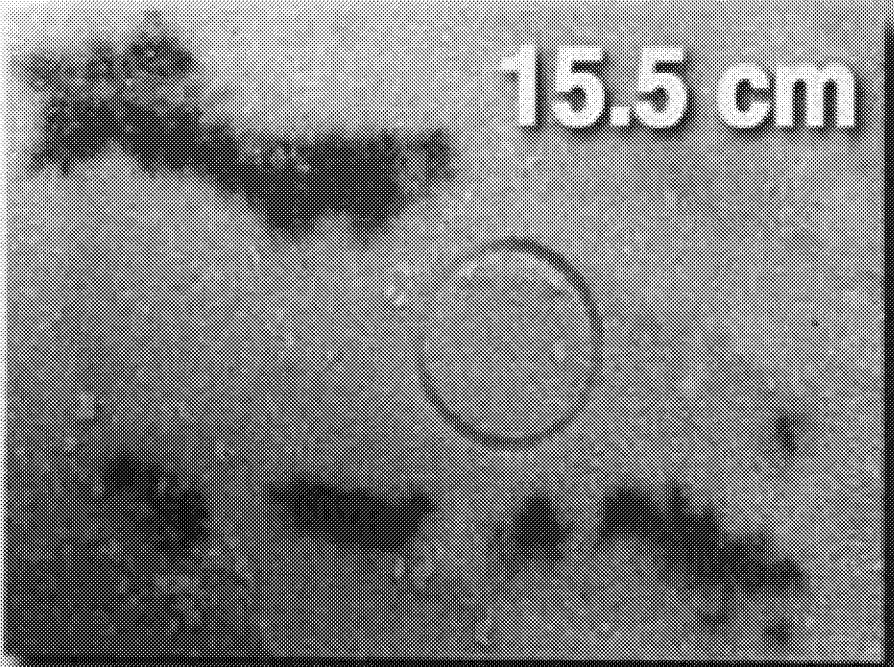
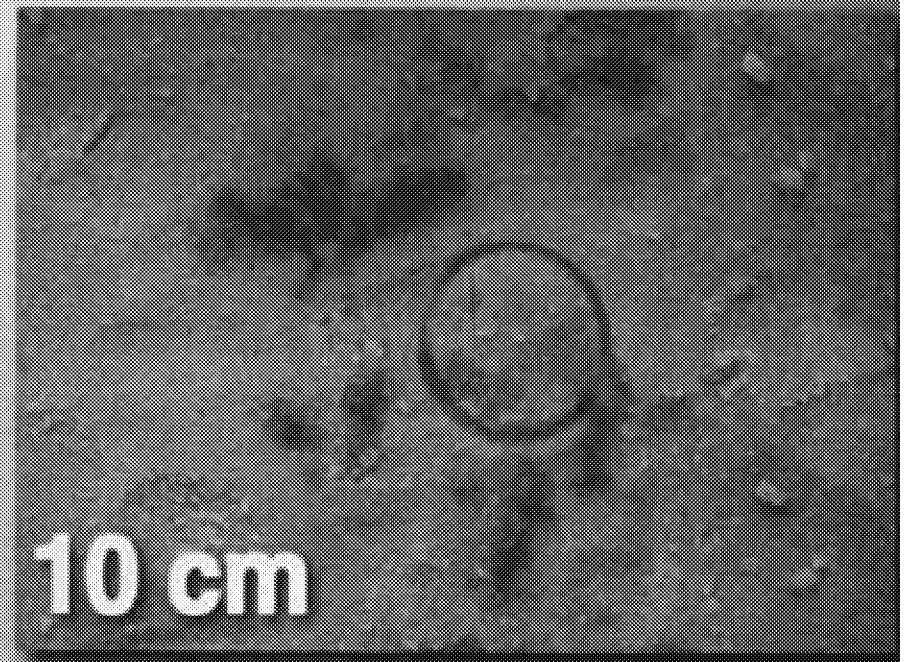
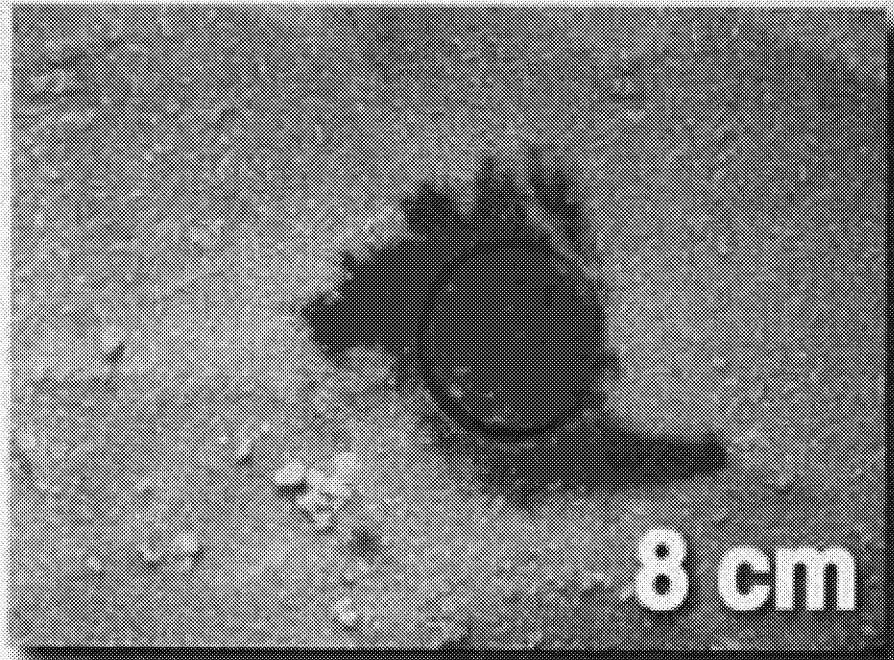


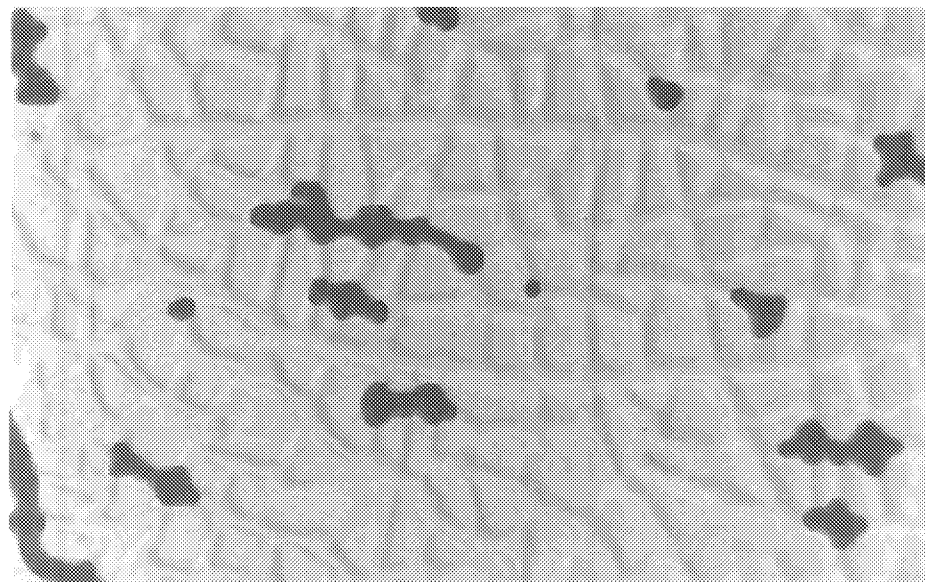
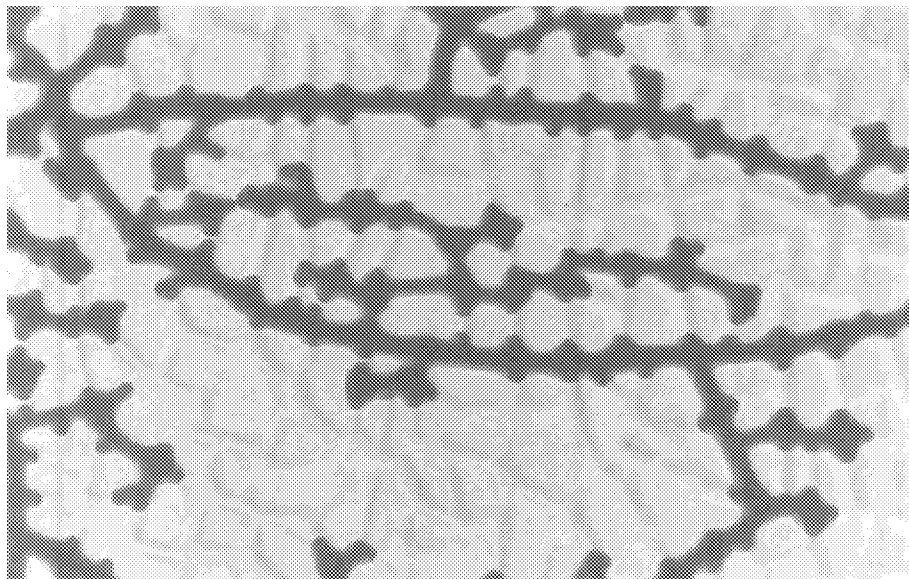
Fig. 4. Residual NAPL saturation, S_{nr} , as a function of initial NAPL saturation, S_{ni} , for the samples of the present study and for the Safety Bay Sand of Steffy *et al.* 1997. Symbols show measured values and lines show the fitted linear regression $S_{nr} = bS_{ni}$.

(From Johnston, C., & Adamski, M., 2005)



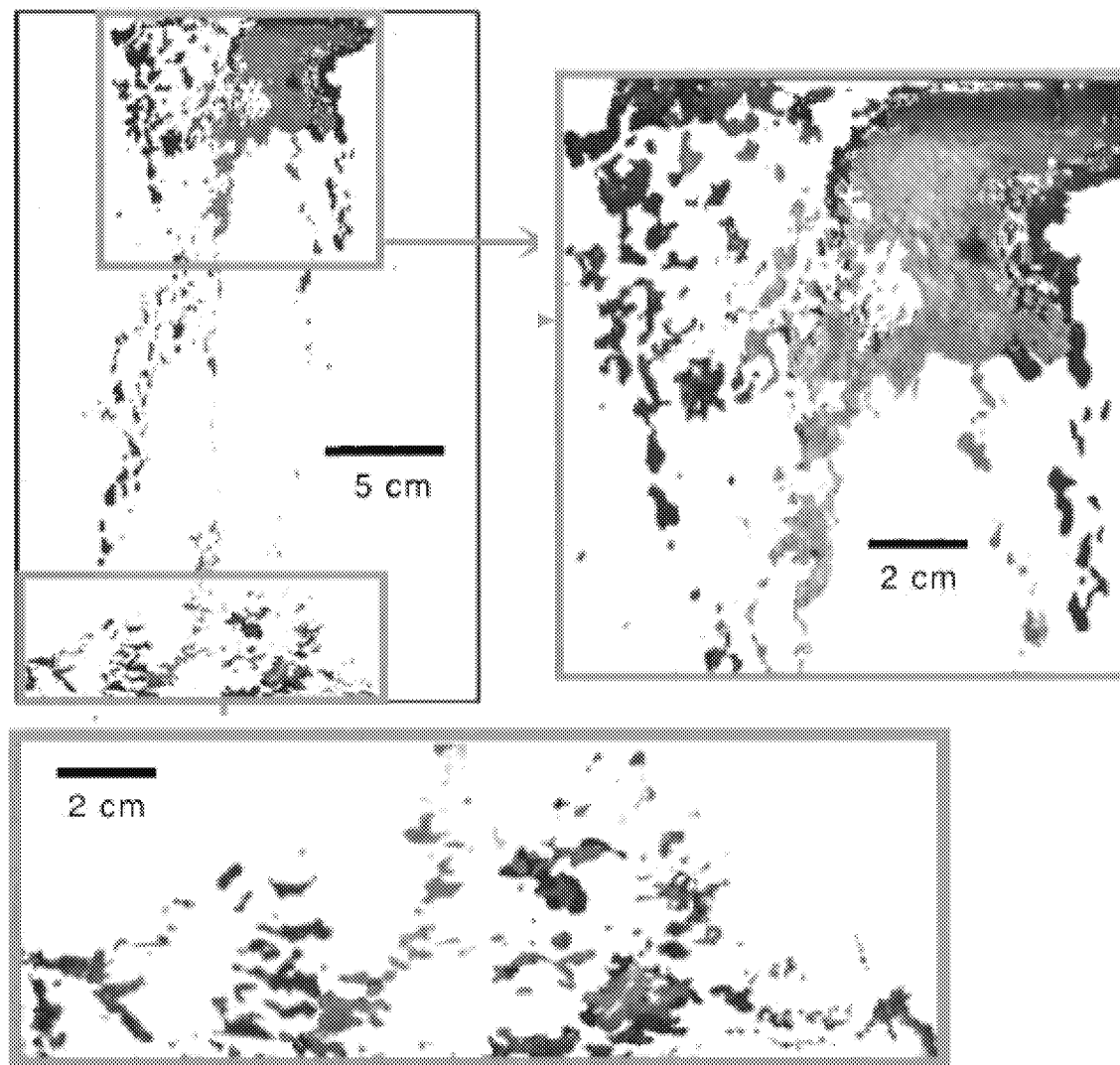
**Johnson 1987
edited by Feenstra 1993**

Oil Displacing Water & Residual Oil



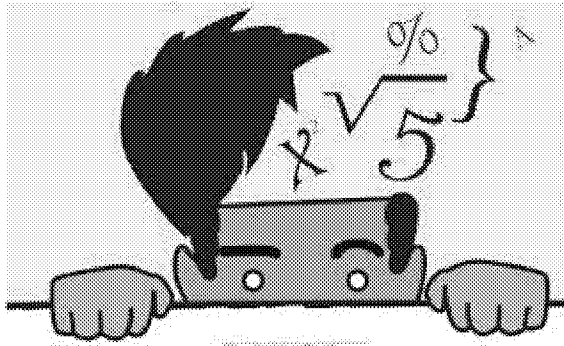
(Source: Wilson et al., 1990; EPA 600/6-90/004)

NAPL Distribution in a Fracture

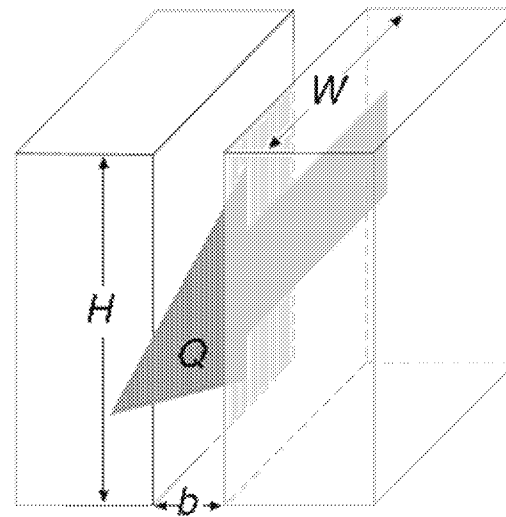


Geller et al., 2000

Just a Little Math... Cubic & Quintic Flow



For “simple” fractures



$$Q = -\frac{\rho g}{12\mu} b^3 \partial h$$

$$K = \frac{2b^2 \rho g}{12\mu}$$

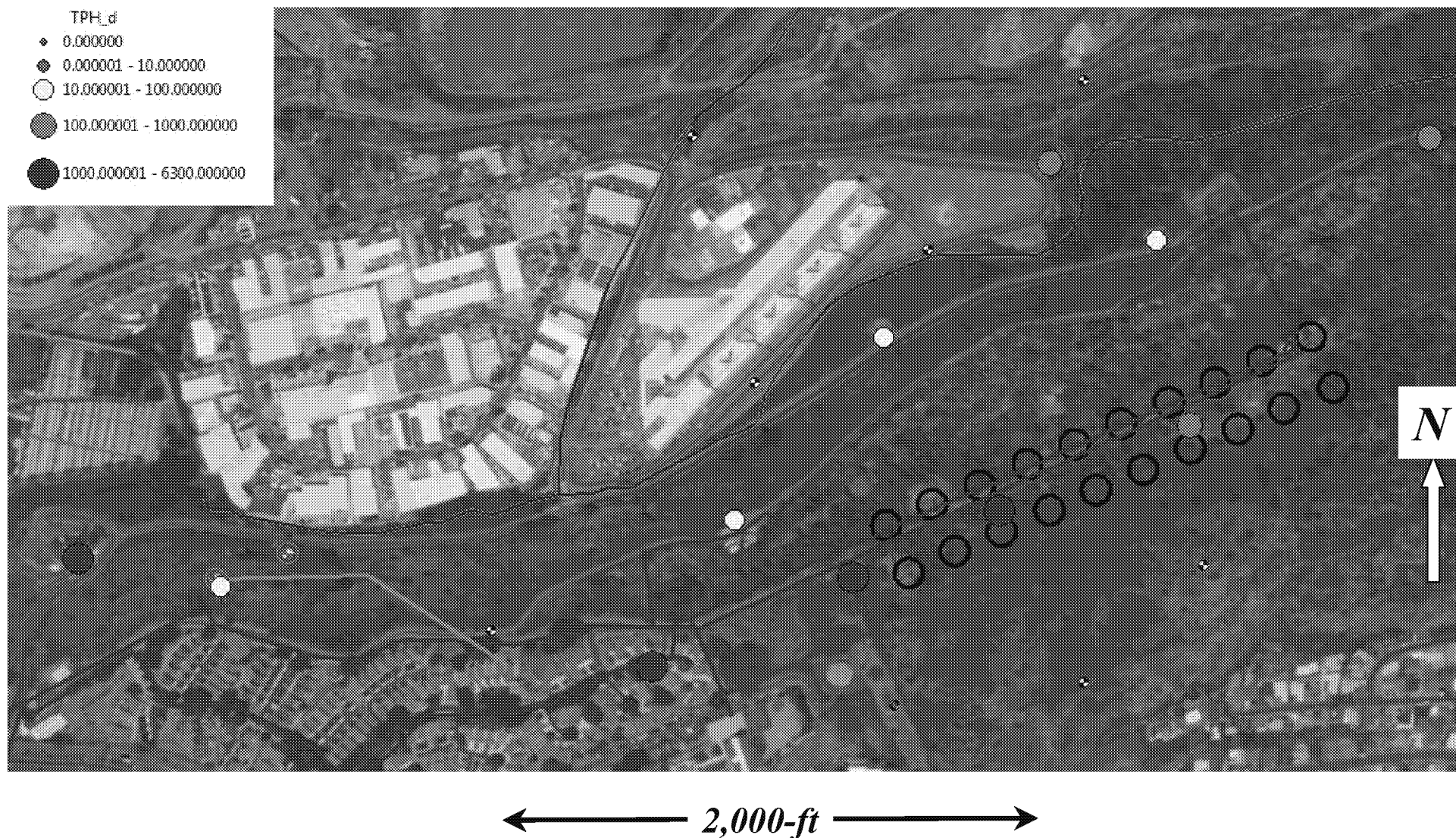
Holy exponential cow!

*Suggested for “real” fractures with
aperture/length correlations*

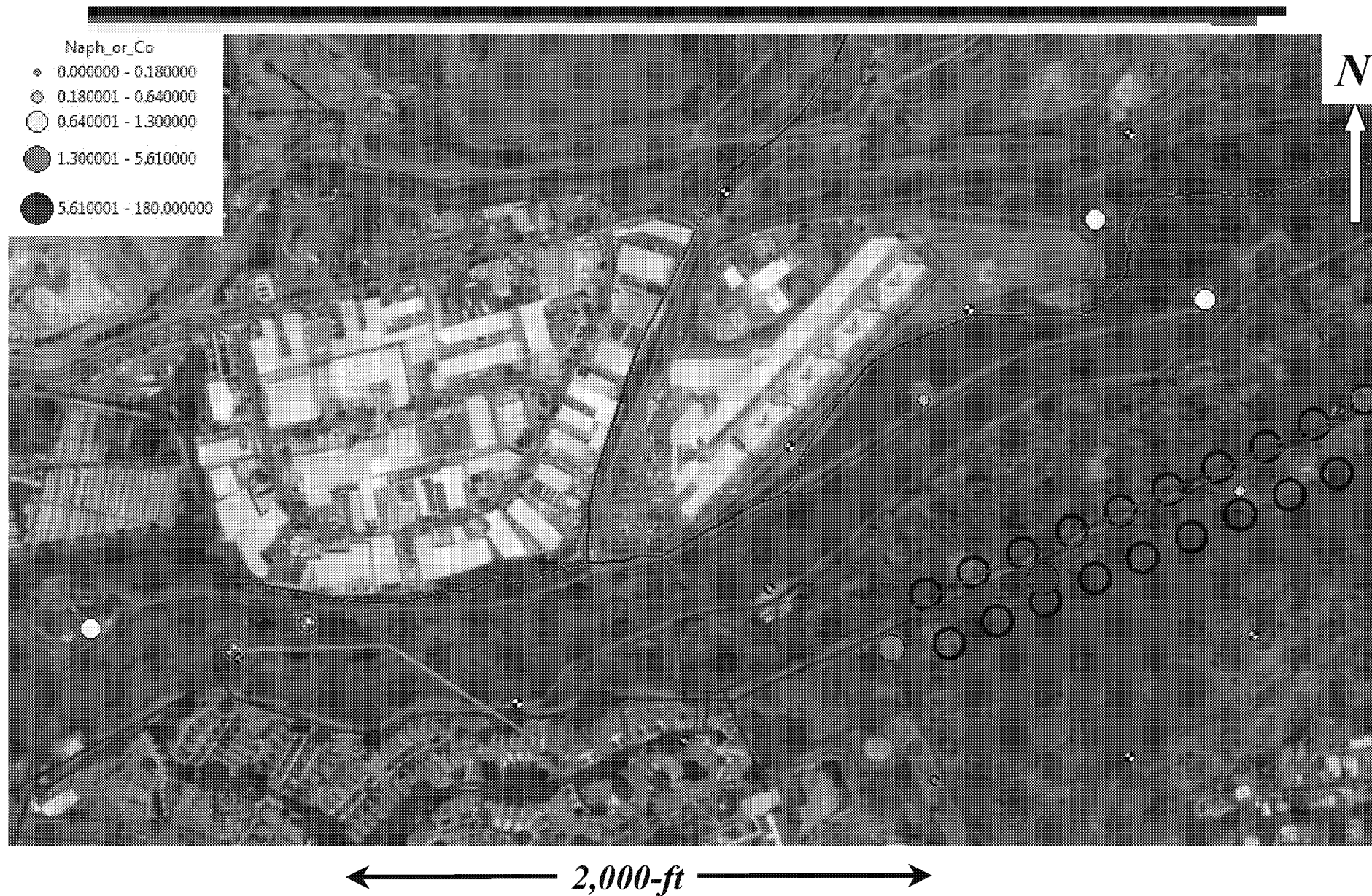
$$Q = -\frac{4\rho g}{3\mu(\pi\alpha)^2} b^5 \partial h$$

after Climczak et al., 2009

TPH_d Maximums in Groundwater



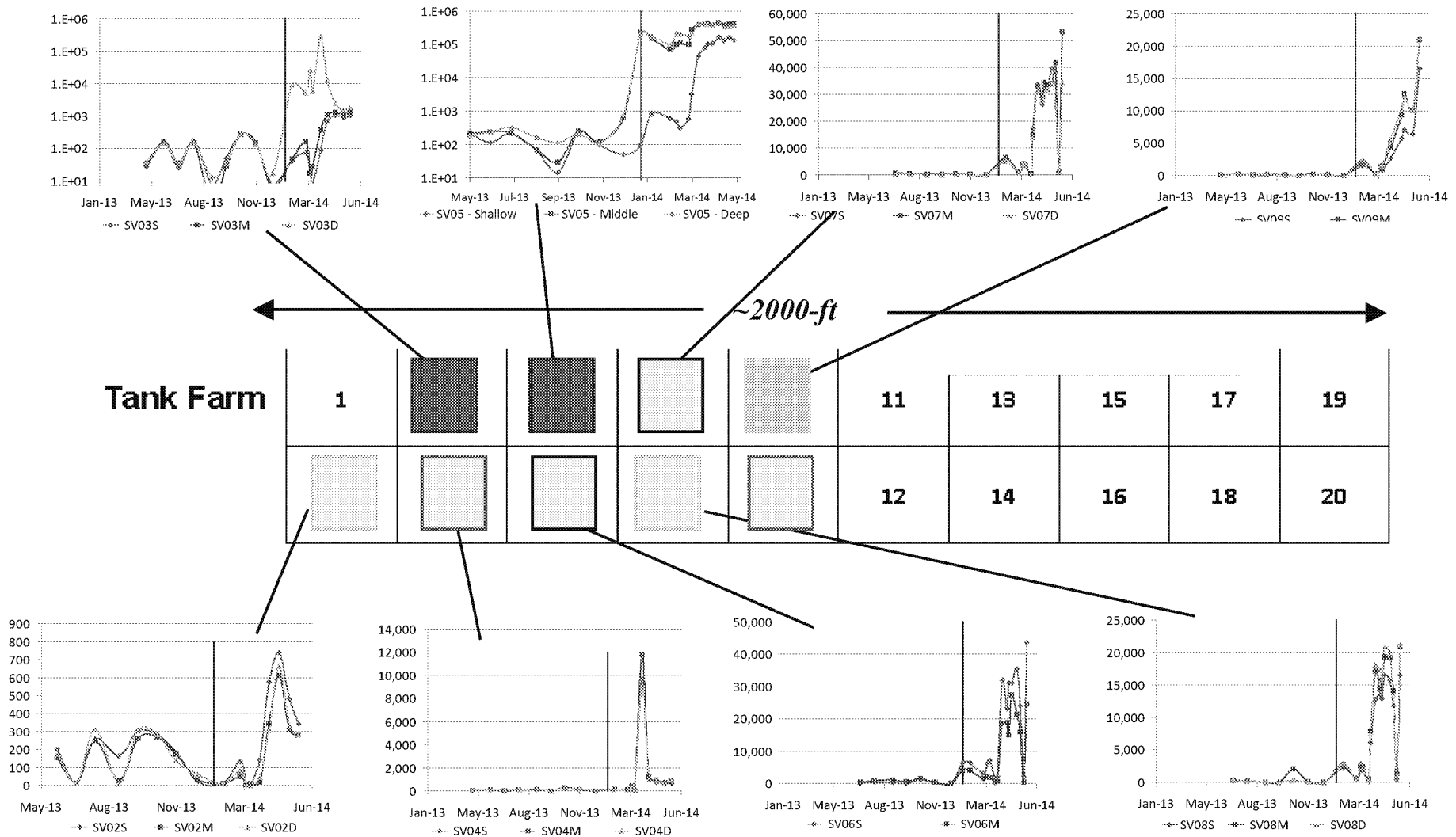
Naphthalene/CoC Maximums in Groundwater



Boring Samples; TPH > 1,000 mg/kg (collected from 1998 – 2001)

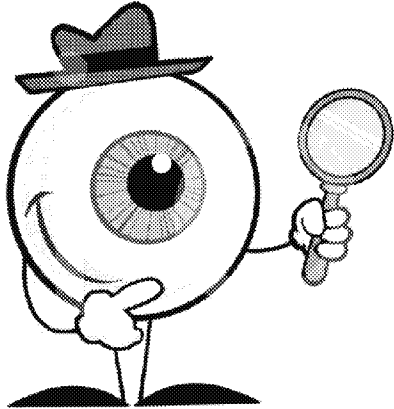
<i>Tank/Boring</i>	<i>Depth (ft) > 50 fbg</i>	<i>TPH mg/kg</i>
B-01	59.6	2,330
B-16C	60	9,400
B-14	60.5	2,090
B-14	60.5	2,810
B-01	61.35	3,300
B-16C	67	4,500
B-11	67.1	1,440
B-16A	83.75	6,600
B-16A	83.75	11,000
B-11	85	2,320
B-11	95	2,910
B-14	95.5	26,200
B-16A	101.83	2,800
B-12	121.9	1,710

LNAPL Range Concentrations in Vapor



Data compiled by Bob Whittier, source; Navy Soil Vapor Reporting

What Can We Surmise from All That?



- There is NAPL in boring samples under tanks
- There has been NAPL in/near groundwater
 - Observations of sheen & blebs (~2010)
- Concentrations in g.w. indicative of NAPL
 - Persistence in tank corridor wells
 - Periodic detections at Red Hill shaft
 - Peak concentration near solubility
 - Pattern consistent with LNAPL source area
 - * Also fast depletion – high flow regime/bio
- Data are internally consistent - conservatively
 - Fuel has potentially reached g.w. in the past
 - Distance of contaminant transport is large
 - Some residual capacity already occupied
 - Uncertainty due to data gaps; time/location